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# Experimental study on combustion optimization of four-corner tangential boiler for alleviating high temperature corrosion

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**Abstract.** In order to reduce the volume fraction of $H_2S$ in the water wall area of the four-corner tangential boiler and achieve the purpose of alleviating the high temperature corrosion of the water wall, a thorough test was carried out on the 600MW boiler. The results show that the high temperature corrosion of the water wall under high load is obviously more serious than that under low load, the high temperature corrosion of the water wall of the front wall is more serious than that of the other walls, and the high temperature corrosion of the furnace wall area downstream of the burner is generally higher than that of the other walls. Other areas. The reason for this phenomenon is that the uniformity of the pulverized coal quantity in each pulverized tube is large, the air distribution is unreasonable, the primary and secondary air are separated, and the secondary air cannot completely cover the primary air; The uniformity of pulverized coal distribution, the proper increase of the total air volume, and the proper increase of the perimeter air volume can significantly reduce the volume fraction of $H_2S$ in the water wall area and alleviate high temperature corrosion.

## 1 Introduction

As the coal price of thermal coal continues to rise, in order to reduce the cost of power generation, power production enterprises have been mixing high-sulfur and inferior coal. However, mixing a large amount of low-quality high-sulfur coal will cause high-temperature corrosion of the water-cooled wall in the boiler burner area, accelerate the thinning speed of the water-cooled wall, and seriously affect the long-term safe operation of thermal power units. At the same time, in order to reduce NOx emissions, power production enterprises have carried out low - nitrogen combustion technology transformation with air graded supply. However, this technology achieves the purpose of reducing NOx by reducing the air supply in the early stage of combustion or delaying the mixing of air and pulverized coal. The burner area is in a state of oxygen-deficient combustion, which inevitably aggravates the high temperature corrosion of the water wall[1-3].

In order to alleviate the high temperature corrosion problem, scholars at home and abroad have carried out a lot of related research, such as corrosion mechanism research,

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burner body optimization research and wall-mounted wind technology research [4-8] , and have achieved fruitful results.

This paper takes a 600MW grade four- corner tangential combustion boiler mixed with high-sulfur and inferior coal as the research object, and carries out the experimental research on combustion optimization adjustment. The influence of H 2 S distribution on the water wall near the wall is expected to provide a solution to the high temperature corrosion problem of this type of boiler.

# 2 Brief introduction of boiler

## 2.1 Boiler condition

The boiler model is SG-1943/25.4-M950. The boiler adopts a Π -type boiler with four-corner tangential combustion. The boiler adopts a positive pressure direct blowing pulverizing system, including 6 medium-speed coal pulverizers, 5 operating at full load. The design fuel of the boiler and the composition of the actual burning fuel are shown in Table 1. The sulfur content of the actual coal used is 3.3 times that of the design coal .

**Table 1.** Design fuel and actual coal composition.

| Coal kind | Car /% | Har /% | $O_{ar}$ /% | $N_{ar}$ /% | $S_{t.ar}$ /% | Mar /% | $A_{ar}$ /% | Vdaf /% | Qnet,ar/MJ/kg |
|---|---|---|---|---|---|---|---|---|---|
| Assume count | 63.13 | 3.62 | 9.94 | 0.70 | 0.41 | 11.5 | 10.70 | 31.13 | 24.14 |
| actual | 56.82 | 3.32 | 9.08 | 0.67 | 1.36 | 15.06 | 13.69 | 33.82 | 21.46 |

Pulverized coal burner adopts four-corner concentric tangential combustion , and part of the secondary air is air classified in the horizontal direction , which delays the mixing of air and pulverized coal to a certain extent in the early stage of combustion.

## 2.2 High temperature corrosion phenomenon

The diameter of the water wall tube in the burner area of the boiler is 38.1mm, the wall thickness is 6.55mm, and the material is SA213-T22. In November 2015, the low nitrogen burner was retrofitted to replace part of the water wall, and in November 2018 , during the shutdown and maintenance, the corrosion resistance The wall thickness measurement of the water wall tube in the severe area was carried out, and it was found through the wall thickness measurement that:

(1) The wall thickness of the most severely thinned water-cooled wall tube is only 3.94mm, and the annual thinning amount reaches 0.87mm, which is significantly higher than the annual thinning amount of 0.35mm calculated before the overhaul, which seriously affects the safe operation of the boiler.

(2) On the whole, the water-cooling wall of the burner area below SOFA has obvious thinning, especially the water-cooling wall of the front wall is the most severely thinned, and there is coking phenomenon, and the black coal powder deposition phenomenon exists in the front wall area.

(3) From the perspective of the horizontal position, the thinning of the furnace wall area of the adjacent corner downstream of the burner is generally higher than that of other areas.

# 3. Situation and cause analysis

## 3.1 The uniformity test of powder quantity of each powder tube under normal working conditions

The primary air-thermal leveling test of the coal mill has been completed, so that the wind speed deviation of each powder pipe of each coal mill is within 5%. Considering that the high temperature corrosion of the front wall is serious, and there is coking phenomenon, and the primary wind speed has been leveled, the basic test of the uniformity of the powder quantity of the primary air powder pipe is further carried out. The specific test method is to keep the load stable, the output of the coal mill and the primary air volume stable, and use a special pulverized coal sampling gun to sample the four powder pipes of each coal mill at the same time. The sampling time is 60s, and the quality difference of the samples is used to judge. The uniformity of powder quantity. The test results are shown in Table 2.

**Table 2.** The deviation % of the powder pipe of each pulverizer.

| Powder tube number | Coal mill | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| Powder Tube 1 | -5.40 | -3.96 | -26.72 | -23.43 | -10.59 | 19.17 |
| Powder Tube 2 | -3.34 | -0.26 | -10.73 | -9.32 | -6.82 | 21.33 |
| Powder Tube 3 | -0.26 | -2.90 | 2.80 | -2.27 | 1.65 | 2.57 |
| Powder Tube 4 | 9.00 | 6.60 | 34.35 | 35.01 | 15.76 | -4.73 |

After testing, it was found that, except for the AB mill, the powder volume of the outlet powder tubes of the six coal mills all had powder tubes with a powder volume deviation of more than 10%. Among them, the powder volume distribution rules of the four powder tubes of C, D and E mills were similar. , both the No. 4 powder tube has the largest amount of powder, the No. 3 powder tube is the second, and the No. 1 powder tube is the smallest. The powder quantity deviation of No. 4 powder tube of C and D mills is the largest, reaching more than 34%. The amount of powder in the No.2 tube of the F mill is the largest, and the amount of the powder in the No. 1 tube is the smallest.

## 3.2 Principle and method of wall-mounted flue gas test

At present , many scholars at home and abroad have conducted in-depth research on the judgment basis of high temperature corrosion [9-10] .The basis for judgment is mainly the sulfur content of fuel and the volume fraction of CO and H2S in the flue gas produced by fuel combustion. Studies have shown that there is a close relationship between high temperature corrosion of boiler water wall and reducing atmosphere, and H 2 S corrosion plays an important role in reducing atmosphere [11] . Based on the positive linear relationship between the volume fraction of H 2 S and the volume fraction of CO, the volume fractions of H 2S and CO are inversely proportional to the volume fraction of O2. So far, the consensus in the industry is that the volume fraction of adherent H2S is less than 200×10 -6 ,and the high-temperature corrosion is controllable. Therefore, the optimization of this paper is based on this standard .

During the maintenance period, flue gas sampling pipes have been installed around the boiler water wall, which are arranged in four layers, with about 12 measuring points on each layer, evenly arranged on four walls, with 3 measuring points on each wall, among which the left and right side walls of the E layer are located. Not installed, a total of 42 measuring points. The specific arrangement is shown in Table 3 . The four layers arranged along the height direction are SOFA layer (layer 4), between SOFA and OFA (layer 3), OFA layer (layer 2), and layer E (layer 1) from top to bottom. Through the measurement of these measuring points, the high temperature corrosion situation of the entire water wall area can be basically understood. When carrying out the test, after the load is stable, the testo 350 flue gas analyzer is used to extract the flue gas through the flue gas sampling pipe, and each measuring point is measured separately.

**Table 3.** Test point layout.

| Layers | Measuring point location | Number of measuring points |
|---|---|---|
| Tier 4 | SOFA layer | 12 |
| Tier 3 | Between SOFA and OFA | 12 |
| Tier 2 | OFA layer | 12 |
| Tier 1 | E-tier burner | 6 |

### 3.3 Wall-mounted flue gas test under conventional conditions

Tested under loads of 600MW, 480MW and 360MW. Only the data are different, so only the test results under the load of 600 MW are listed, as shown in Table 4.

**Table 4.** Volume fraction of $H_2S$ at each measuring point of 600MW load.

| Measuring point location | project | front wall | | | left wall | | | back wall | | | right wall | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | point 1 | point 2 | point 3 | point 4 | point 5 | point 6 | point 7 | point 8 | point 9 | point 10 | point 11 | point 12 |
| Tier 4 | $\varphi(H_2S)/10^{-6}$ | 500 | 462 | 500 | 155 | 50 | 178 | 167 | 189 | 202 | 65 | 50 | 94 |
| Tier 3 | $\varphi(H_2S)/10^{-6}$ | 500 | 500 | 500 | 110 | 96 | 120 | 190 | 210 | 140 | 112 | 107 | 135 |
| Tier 2 | $\varphi(H_2S)/10^{-6}$ | 368 | 357 | 395 | 76 | 106 | 115 | 180 | 160 | 160 | 60 | 70 | 86 |
| Tier 1 | $\varphi(H_2S)/10^{-6}$ | 123 | 164 | 202 | / | / | / | 177 | 142 | 168 | / | / | / |

Comparing the 600MW, 480MW, and 360MW loads, the flue gas composition near the water wall can be seen as follows:

With the increase of load, the volume fraction of $H_2S$ increases. Under the loads of 600 , 480 and 360 MW , the average $H_2S$ volume fractions of all measuring points are $200.98\times10^{-6}$ , $165.48\times10^{-6}$ and $110.36\times10^{-6}$ , respectively, and the corresponding H2S volume fraction exceeds 0.02% The number of measuring points are 12 , 10 and 6 respectively

(2) The volume fraction of H 2 S in the water-cooled wall area of each wall : the volume fraction of H2S in the water-cooled wall area of the front wall is significantly higher than that of other walls, followed by the rear wall, and the lowest $H_2S$ volume fraction of the left and right walls ; In terms of the distribution of $H_2S$ volume fraction in the wall water wall area , the front wall is close to corner 1 (point 2, point 3) , the left wall is close to corner 2 (point 6) , the rear wall is close to corner 3 ( point 9 ) , and the right wall is close to corner 3 (point 9). Near corner 4 ( point 12 ) , generally higher than other areas. This is consistent with the corrosion and thinning of the water wall and the severe coking of the front wall found in the shutdown inspection.

### 3.4 Cause analysis of high temperature corrosion

(1) Influence of coal quality into furnace

The sulfur mass fraction of the actual coal used in the boiler is 1.36%, which is 3.3 times that of the designed coal, which belongs to high-sulfur coal. Studies have shown that the sulfur content of the coal has a significant impact on high-temperature corrosion, and the sulfur content is related to combustion. The H 2 S produced is proportional to the free state S.

(2) Influence of reducing atmosphere

The low-nitrogen burner of the boiler is retrofitted with air classification technology, and the burner area is in a state of oxygen-deficient combustion, which inevitably aggravates the high-temperature corrosion of the boiler's water wall.

(3) Influence of powder distribution uniformity

The weight distribution uniformity test of each powder tube found that, except for the AB mill, there were powder tubes with a powder deviation of more than 10%. The deviation of the powder amount of each powder pipe increases the momentum difference of the four corners of the air entering the furnace, causing the deflection of the flame center, and even the coal powder painting the wall; The amount of powder in individual powder tubes is too large, which leads to a certain degree of local hypoxia, which intensifies the reducing atmosphere in the relevant area.

(4) Influence of boiler air distribution

The boiler is concentric tangential combustion, that is, the primary air tangent circle is small, the secondary air tangent circle is large, the primary air pulverized coal is wrapped in the center of the furnace by the secondary air of the outer ring, and the air around the water wall is enriched near the wall. The air distribution method can reduce the deposition of ash and slag on the wall and reduce the high temperature corrosion of the water wall. However , in order to control the total NOx generation, the total air supply volume is too small, coupled with the small opening of the secondary air door in the main combustion area, the power of the secondary air entering the furnace is insufficient , the speed decays rapidly, and the primary air powder flow is not affected. When the wrapping effect is reached, the primary and secondary air cannot be fully mixed, and there is a local reducing atmosphere in the water wall area downstream of the jet, and the $H_2S$ generated by the combustion of pulverized coal in an oxygen-deficient state is high, resulting in high temperature corrosion .

## 4 Combustion optimization test

### 4.1 Optimization test of pulverized coal uniformity in primary air pulverized pipe

Adjust the opening of the pulverized coal distributor of the coal mill to change the distribution of the powder volume of the four powder pipes, and finally ensure that the deviation of the primary air speed is less than 5%, and the deviation of the powder volume of the primary air powder pipe is less than 10%. Through the adjustment of the pulverized coal distributor of the pulverizer, the deviation of the pulverized amount of each pulverizing tube can basically reach the requirement of less than 10% except for the E mill. On this basis, the adherent reducing atmosphere under different load conditions was tested .

Optimizing and adjusting the non-uniformity of pulverized coal distribution in the pulverized tube , the $H_2S$ in the front wall adhering area under two different loads both decreased significantly. Under the load of 600MW, the number of measuring points with $H_2S$ volume fraction exceeding 0.02% was reduced to 1. The average $H_2S$ of the water-cooled wall measuring points on the front wall is reduced to 30.0% before optimization; under 360MW load, the measuring points with the volume fraction of $H_2S$ exceeding 0.02% are reduced to 0, and the average $H_2$ of the water-cooling wall measuring points on the front wall S is reduced to 50.0% before optimization. Through adjustment, it is found that the uniformity of pulverized coal in each pulverized tube has an important influence on the high temperature corrosion of the water wall. During operation, attention should be paid to the uniformity of pulverized coal in each pulverized tube of the same layer burner.

### 4.2 Total air volume optimization test

When the air distribution method remains unchanged, increasing the total air volume can increase the secondary air volume in the main combustion area, improve the kinetic energy and rigidity of the secondary air, on the one hand, strengthen the isolation of the secondary air from the primary air and the water wall, and on the other On the one hand, the reducing atmosphere in the water wall area is relieved, and the conversion ratio of $H_2S$ to $SO_2$ is improved.

High temperature corrosion basically exists in the high load condition of 600MW load, so only the optimization adjustment test is carried out for this load. Experiments were carried out under five operating conditions of oxygen content of 2.0 %, 2.5%, 3.0%, 3.5%, and 4.0%. The $H_2S$ volume fraction of the measurement points under the 600 MW load after optimization of the distribution uniformity of pulverized coal in Section 3.2 was greater than 0.02% of the measuring points are monitored. Table 5 gives the volume fraction of $H_2S$ at different total air volumes.

**Table 5.** H 2 S volume fraction under different total air volume.

| Oxygen volume fraction/% | Average $H_2S$ volume fraction/× $10^{-6}$ | Average volume fraction of key monitoring points / $10^{-6}$ | The number of measuring points for $H_2S$ exceeds $200 \times 10^{-6}$ |
|---|---|---|---|
| 2 | 161.1 | 318.8 | 9 |
| 2.5 | 150.4 | 234.8 | 4 |
| 3 | 139.6 | 206.5 | 4 |
| 3.5 | 132.9 | 200.1 | 5 |
| 4 | 103.5 | 141.2 | 2 |

With the increase of oxygen content, the volume fraction of $H_2S$ in the wall area decreases rapidly, and the number of measuring points exceeding 0.02% gradually decreases. However, with the increase of the total air volume, the amount of $NO_X$ generated will increase ; in addition , the amount of flue gas will also increase, and the heat loss of exhaust gas will also increase , but increasing the total air volume can improve the carbon burnout rate. In order to study the influence of total air volume on boiler emissions and boiler efficiency, the boilers were tested under different total air volumes. The specific test results are shown in Table 6.

Combined with the comparison of boiler efficiency and $NO_X$ generation concentration under each total air volume, the optimal oxygen volume fraction was finally determined to be 3.0%.

**Table 6.** Boiler efficiency and NOx generation mass concentration under different total air volumes.

| parameter | Economizer inlet oxygen volume fraction /% | | | | |
|---|---|---|---|---|---|
| | 2 | 2.5 | 3 | 3.5 | 4 |
| Fly ash combustibles/% | 1.96 | 1.69 | 0.96 | 0.6 | 0.58 |
| Slag combustibles/% | 5.6 | 4.92 | 4.53 | 3.91 | 3.76 |
| Corrected thermal efficiency/% | 93.53 | 94.02 | 94.09 | 93.92 | 93.84 |
| Economizer outlet NOx (6% $O_2$) concentration/(mg.m $^{-3}$) | 154.6 | 168.8 | 181.4 | 203.5 | 246.1 |

### 4.3 Ambient wind optimization test

The designed peripheral air volume of the low-nitrogen burner accounts for 10% of the total air volume, but in order to control the concentration of $NO_X$ generation, the opening degree of the peripheral air is generally set to be small , so the oxygen volume fraction is set to 3.0% , and the optimization test of the peripheral wind is carried out. , and the test results are shown in Table 7.

**Table 7.** H 2 S volume fraction, boiler efficiency and NO X generation mass concentration under different perimeter air volumes.

| parameter | Peripheral wind opening/% | |
|---|---|---|
| | 50 | 80 |
| Average $H_2S$ volume fraction / $10^{-6}$ | 139.6 | 108.0 |
| Average volume fraction of $H_2S$ at key monitoring points / $10^{-6}$ | 206.5 | 171.5 |
| $H_2S$ exceeds 0.02% | 4 | 3 |
| Fly ash combustibles /% | 0.96 | 1.45 |
| Slag combustibles /% | 4.53 | 4.98 |
| Corrected exhaust gas temperature /℃ | 128.039 | 126.037 |
| Corrected thermal efficiency /% | 94.09 | 94.08 |
| Economizer outlet NOx (6%$O_2$) concentration/(mg.m $^{-3}$) | 181.4 | 185.2 |

It can be seen from the test that increasing the peripheral air volume can effectively reduce the generation of H 2 S in the water wall area . Increasing the perimeter air volume can, on the one hand, supplement the amount of oxygen for pulverized coal combustion and reduce the generation of reducing atmosphere; Wall risk, and take advantage of low-nitrogen burner air-encapsulated powder. In addition, the test found that after the opening of the perimeter air was increased to 80%, the left and right side deviation of the screen superheater outlet was significantly reduced, from the original 14°C to within 7°C, the outlet of the final superheater and the outlet of the final reheater were significantly reduced. The steam temperature deviation on both sides is within 0.5°C, and when the perimeter air opening is 50%, the steam temperature deviations at the end of the pass and the end of the recycle are both between 3 and 4°C. it has been improved.

Under the load of 600MW, the peripheral air volume is increased, the opening of the peripheral air damper is increased from 50% to 80%, the exhaust gas temperature is reduced by 2.0°C after the correction, the exhaust heat loss is reduced, and the heat loss of unburned carbon is slightly increased. From the point of view, the change of boiler efficiency is not obvious, and the change of $NO_X$ emission concentration is also not obvious, with a slight increase of 3.8 mg/$Nm^3$ .

It can be seen that due to the small proportion of the perimeter air volume to the total air volume, increasing the perimeter air volume has little effect on the boiler efficiency and $NO_X$ generation . Under the load of 600MW, the opening degree of the perimeter air is set to 80% optimally .

Through the above optimization, the volume fraction of adherent $H_2S$ is significantly reduced , the average volume fraction of $H_2S$ is only $108.0 \times 10^{-6}$ , and there are only 3 measuring points with more than 0.02%. The $NO_X$ generation amount increased slightly, and the $NO_X$ generation mass concentration at the inlet of the selective catalytic reduction denitrification system increased from about 154.6 mg / $m^3$ to about 185.2 mg / $m^3$ .

## 5 Conclusions and recommendations

(1) The high-temperature corrosion of the water-cooled wall under high load is significantly

greater than that of the low-load, and the high-temperature corrosion of the water-cooled wall of the front wall is more serious than that of other water-cooled walls; the high-temperature corrosion of the adjacent corner furnace wall area downstream of the burner is generally higher than that of other areas. .

(2) The high-temperature corrosion of the water-cooled wall of the front wall is more serious than that of the water-cooled walls of other walls, which is caused by the large deviation of the pulverized coal uniformity of each pulverized tube. During operation, attention should be paid to the amount of pulverized coal in each powder tube of the same layer of burners. If necessary, the pulverized coal distributor of the pulverizer can be added to improve the uniformity of pulverized coal distribution in each pulverized tube.

(3) The high-temperature corrosion in the adjacent corner furnace wall area downstream of the burner is generally higher than that in other areas . This is because the primary air powder deviates from the secondary air, and the pulverized coal is burned with insufficient oxygen, forming a local reduction in the water wall area downstream of the jet. Atmosphere, resulting in high $H_2S$ generated, resulting in high temperature corrosion.

(4) Adjusting the pulverized coal uniformity of the primary air powder pipe, appropriately increasing the total air volume, and appropriately increasing the peripheral air volume can significantly reduce the volume fraction of $H_2S$ in the water-cooled wall area and alleviate high-temperature corrosion.

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